# EVALUATION OF BITUMINOUS PAVEMENTS FOR HIGH PRESSURE TRUCK TIRES


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## INTRODUCTION

In recent years several states in the United States have experienced premature rutting of hot mix asphalt (HMA) pavements due to increased traffic loads and/or increased truck tire pressures. Current pavement designs are based on 18,000 lb-axle loads and contact pressure of **75** psi. Recent legislation has increased the legalized loads. There are no laws governing the maximum tire inflation pressure.

Recent surveys in Illinois and Texas indicate that the tire pressures have increased substantially. Tire pressures averaged 96 psi with a maximum of 130 psi in the Illinois survey. Texas survey showed an average of 110 psi with a maximum of 155 psi. Recent studies in Texas also indicate that a tire inflation pressure of 90 psi can cause very high pressures (over 200 psi) near the tire shoulder region.

The Pennsylvania Department of Transportation's first major asphalt pavement rutting was experienced on Interstate 70 in Washington County during early summer of 1986. Additional cases of rutting have occurred since that time. A special provision for designing the HMA mixtures for heavy duty pavements was developed by the Pennsylvania Department of Transportation (PennDOT) and implemented in 1987. However, there was a need to evaluate several heavy duty pavements constructed in the past with and without the special provision so that the pavement properties (materials, mixture design, construction and post construction) which typify good and bad pavements could be identified. This will facilitate further changes to PennDOT's current material specifications, mix design, and construction procedures to cope with the increased truck loads and/or tire pressures. This will also identify which items contained in the special provisions are significantly more effective in minimizing or eliminating premature rutting.

## HISTORY AND BACKGROUND

About 57 percent or 25,000 miles of interstate highways in the United States have HMA surface. Premature rutting of heavy duty HMA pavements was first experienced as a major problem in WASHTO (Western Association of State Highway & Transportation Officials) states during the late 1970's. WASHTO members discussed this problem in 1983 and issued a report in 1984 (1). Before this time most states in the eastern United States including Pennsylvania had not experienced any significant rutting. First major incidence of rutting was reported in 1984 in Virginia and Florida. Pennsylvania, Tennessee and New Jersey Turnpike experienced rutting for the first time in 1986. Illinois had experienced some rutting on 3" HMA overlays over PCC pavements since 1979. However, the problem in Illinois became more serious in 1984.

All these developments made the asphalt paving technologists wonder as to why the rutting is being experienced now when in the past the HMA pavements had an excellent performance record on heavy duty highways. The change in scenario can be attributed to the following factors as a minimum:

- Increased truck volume
- Increased truck loading
- Increased tire pressure
- Increased number of HMA overlays over existing PCC pavements
- Channelized traffic during construction

The following FHWA highway statistics (2) for a typical rural interstate highway in the United States for the period 1970 to 1984 are of interest.

| | Increase during 1970 to 1984 |
|---|---|
| No. of total vehicles | **20%** |
| **No.** of trucks | 49% |
| No. of **18-kip** equivalent single axle loads **(ESAL's)** | 126% |

During these 14 years, the number of total vehicles including cars increased by 20 percent. However, the significant thing is that the number of trucks (90 percent of which have 5 or more axles) increased by 49 percent during this period. Even more significant than this is that the number of **ESAL's** (equivalent 18-kip single axle load applications per day) increased by 126 percent. That is an average increase of 9 percent per year. What it means is that the load anticipated in 20 years was applied to the pavement in 8-10 years' time in many cases. In other words, the design life of the HMA pavement was reduced from 20 to 8-10 years.

Along with the increased truck loading increased tire pressures were also experienced in recent years. During AASHTO Road Tests in the 1950's the tire pressure was 75-80 psi which formed the basis for pavement analytical distress models. However, recent surveys in Illinois and Texas show that the average tire pressures have increased significantly. In Illinois' study, the average tire pressure was 96 psi and the maximum was 130 psi. In Texas' study, the average tire pressure was **110** psi and the maximum was 155 psi.

Not only has tire pressure increased but its nonuniform distribution over the contact area has compounded the problem **(3).** Figure 1 shows an actual pressure print of a loaded tire. Lighter color areas indicate higher pressure compared to gray areas. The pressure in the shoulder region of the tire is more than twice the inflation pressure. This nonuniform pattern of pressure has resulted from stiffer sidewall and shoulder design of the tires. Incidence of a dual rut associated with the tandem tires can be attributed partly to this changed tire design.

There was so much concern about this changing scenario that the AASHTO organized a National Workshop on High Pressure Truck Tires which was held in Austin, Texas in February 1987. The workshop concluded that the load changes remain outside the influence of the highway engineers. However, design and construction of HMA pavements could be adapted to meet the changing conditions.

It is quite possible that we will see a further increase in the tire pressures. Increased tire pressures reduce the rolling resistance and, thus, reduce fuel costs for the trucking industry. Tire technology already exists to design and manufacture tires having higher inflation pressures. The U.S. Navy currently uses tires on their fighter planes that are inflated to 400 psi. An increase in the number of axles, say from 5 to 7, is envisioned. This increase in number of axles will reduce pavement stresses and thus will be a relief to the highway design engineer. This is already being considered at the national level.

Many PCC pavements of interstate and primary highways which were designed for 20 years are deteriorating before the design life. Recent years have seen increased HMA overlays over these existing PCC pavements. Illinois' study (4) has shown that excessive shear deformation occurs in HMA overlays underlain by PCC pavements. Channelized traffic can also induce rutting just after construction especially if the mat is still hot. Figure 2 shows two-way bumper to bumper traffic on two recently overlaid lanes of an interstate highway while the other two lanes are under construction.

As mentioned earlier, PennDOT's first major HMA pavement rutting was experienced on Interstate 70 in Washington County during early summer of 1986 (Figures 3 and 4). Additional cases of rutting were reported later. The Department developed a special provision for designing the HMA mixtures for heavy duty pavements to minimize rutting (5). This special provision was made applicable in 1987 to the wearing, binder and base course mixtures used on the main line, ramps and cross-overs of all Interstate highways, and other highways carrying more than 20,000 ADT (average daily traffic) or more than 1,000 daily 18 kip equivalent single axle load (ESAL) applications. The salient features contained in the special provision are:

1. Use of larger size aggregate for binder and base course mixtures. Previously, AASHTO No. 57 (1 in. to No. 4) aggregate was generally used. Use of AASHTO No. 467 (1-1/2 in. to No. 4) was recommended.
2. More angular coarse aggregate. Previously, the gravel coarse aggregate in the binder course was required to have at least 50 percent with one fractured face. This was increased to at least 85 percent with two or more fractured faces which was the same as the wearing course.
3. At least 75 percent manufactured sand in the fine aggregate. Research in the past has shown that the manufactured sand is generally angular and its incorporation in the mix resists rutting.
4. At least 4 percent minus No. 200 fraction in the mixture to stiffen the asphalt binder. The maximum permissible percentages of minus No. 200 in the job-mix formula was kept the same as previously specified (6 and 5 percent for wearing and binder mixtures, respectively).
5. Marshall specimens to be made with 75 blows on each side.
6. Minimum voids in the mineral aggregate (VMA) was kept the same as previously specified (16 and 13 percent for wearing and binder mixtures, respectively).

7. Marshall stability to be 2,150 lb. minimum for all courses. Flow of 6 to 16 was kept the same.

Of the 34 total pavements evaluated in this research project, seven pavements were constructed using the preceding special provision for heavy duty pavements.

Based on the recommendations of the PennDOT/industry task force on rutting, the special provisions were revised in October 1988 as follows:

1. Marshall stability at 140°F not less than 2000 lbs. in the job-mix formula and not less than 1800 lbs. during production,
2. Percentage of unfilled voids to be 4.0 and 4.5 percent for wearing and binder mixes, respectively, for the reviewed job-mix formula. Voids in plant compacted Marshall specimen not to exceed the master range of 3.0 to 6.0 percent for wearing, and 3.5 to 6.5 percent for binder mixes. Compliance for this criteria is acceptable if 90 percent of the determinations per project are within the stated tolerance band,
3. The binder course mix gradation revised so that 100 percent passes 2" sieve, 95 to 100 percent passes 1 1/2' sieve, 85 to 95 percent 1" sieve and 40-65 percent passes 1/2" sieve in the job-mix formula.
4. The requirement for minimum minus 200 content of 4 percent was deleted, and
5. The wearing course should not be placed if it will be subjected to high temperatures and channelized traffic for extended periods of time until all binder courses have been completed.

## OBJECTIVES

The primary objective of this research project was to evaluate 34 in-service heavy duty pavements to identify the material properties, mix design parameters, pavement construction properties, and pavement in-service properties which are responsible for the premature rutting (permanent deformation) of some HMA pavements. A threshold analysis was performed to determine if the measured parameters have a threshold value which separates acceptable and unacceptable performance. The preceding information will be helpful to PennDOT in revising the specifications for heavy duty HMA pavements.

## DATA COLLECTION, SAMPLING AND TESTING PLAN

Thirty-four (34) heavy duty pavements encompassing poor to excellent performance in terms of rutting were identified by Penn DOT. All pavements except two (Sites 5 and 31) met PennDOT's criteria for heavy duty pavements mentioned earlier.

A special effort was made in selecting pavements which had the best and most readily available test data, specifically projects constructed under the Department's restricted performance specifications. This was done to facilitate the correlation of as-constructed pavement properties with rutting.

### Data Collection

An attempt was made to collect the following data on all projects from the Engineering District Offices (District Materials and Construction Engineers) and the Materials Testing Division (MTD) of the PennDOT's Bureau of Construction and Materials.

1. State Route (S. R.) Number and stations
2. Geographical location

3. Average climatic conditions

4. General topography (including grades)

5. Average daily traffic (ADT) including the percentage of trucks, and 18-kip equivalent single axle loads (ESAL) per day.

6. Details of underlying pavement structure such as, type (flexible or rigid, base course, binder course, wearing course), thickness, material type and condition.

7. Details of new construction or overlay such as, thickness and type of bituminous concrete base course (BCBC), levelling or scratch course, binder course and **wearing course.**

8. Dates of construction for various courses in all lanes and the prevailing weather renditions.

9. Traffic management during construction such as, the time and duration when certain lanes or segments of the roadway were subjected to two-way or increased traffic intensity, use of barrier or curb, extent of channelization, cross-overs, and how soon road opened to traffic.

10. Job-mix formula (JMF) including the Marshall design data at various asphalt contents used for determining the optimum asphalt content, aggregate sources and types (stone, gravel, slag, manufactured or natural fine aggregates, crush count, etc.), and asphalt grade used.

11. Construction data including daily plant reports to determine the following:

(a) Construction dates and prevailing weather conditions

(b) Type of mix plant

(c) Compaction equipment and rolling procedures

(d) Daily mix and Marshall test data such as, extraction results, hot bin gradation, specimen specific gravity, theoretical maximum specific gravity, % air voids, % VMA, stability and flow

(e) Penetration and viscosity of asphalt cement used

12. Special features of the project such as, long steep grades, and intersections or exits causing frequent slowing or stopping of traffic.

13. RPS (Restricted Performance Specification) data showing the mix composition and percent compaction obtained in all lots and sublets of the project along with the delineation (starting and ending stations) of lots, and location of sublot samples (particularly core samples)

14. Quality assurance (QA) sample test data

Complete data could not be obtained for some pavements which are very old and, therefore, records are not available.

**Sampling and Testing Plan**

Eleven 6-inch diameter cores were to be obtained from a representative one lane mile segment (travel lane) of each project (Fig. 5). However, Penn DOT decided to select the worst segment (maximum rutting) of the project for taking these cores. On some projects, considerations for sight distance and safety precluded coring the worst sites. All cores were taken during spring of 1989. Five cores numbered Cl -C5 were obtained at random locations from the inside wheel track of this segment. These five cores from each project (total 170 cores) were tested as follows:

1. Thickness of layers (all cores)
2. Bulk specific gravity (all cores)
3. Theoretical maximum specific gravity
4. Extraction - asphalt content and gradation (all cores)
5. Recovered coarse aggregate (retained on No. 4 sieve) - crush count (one core)
6. Recovered fine aggregate - particle shape and texture (determined in terms of percent void content using the National Aggregate Association procedure given in Appendix "C").

Five additional 6-inch diameter cores (C7-C11 ) were obtained across the pavement two feet center to center at the worst (maximum rutting) location of the selected segment as shown in Fig. 5. The testing program for these cores is shown in Fig. 6. Essentially, the following tests were run:

1. Bulk specific gravity of layers (all cores)
2. Static unconfined creep test (2 cores)
3. Bulk specific gravity, stability and flow tests were run on two specimens each recompacted by three compaction methods: (a) Gyratory testing machine **(GTM),** (b) Rotating base, slanted foot mechanical Marshall compactor, and (c) Static base conventional mechanical Marshall compactor.

The thickness of all layers in Cores C7-C11 was accurately measured before sawing the layers. These thicknesses were used to obtain the profiles of the underlying layers once the surface profile was established. Bulk specific gravity of all layers in these cores was obtained to determine the in-place voids in the total mix (VTM) at each location.

Two cores were subjected to unconfined static creep test using the Shell method using the MTS machine shown in Fig. 7. The cores were heated to 104°F for two hours and then loaded in the environmental chamber (104°F) of the MTS for testing. Teflon disks, approximately 1/1 6 inch thick by 6 inch diameter, were placed at the ends of the sample to reduce the effects of friction. The samples were then preloaded to 30 pounds for two minutes. At the end of the preload the load was increased to 425 pounds and held constant for 1 hour and the vertical deformation of the sample was recorded continuously. After one hour the load was removed. The rebound was not recorded.

After the creep tests on two cores all five cores were warmed to crumble the mix and then reheated to 275°F for compaction. Two 4"-diameter specimens each were compacted using the three compaction methods mentioned earlier. The Gyratory testing machine (U.S. Corp of Engineers) or GTM shown in Fig. 8 was used. The machine was set at 120 psi (typical of today's truck tire pressures), 1 degree angle, and 300 revolutions. Past experience has shown that this compactive effort provides a specimen having density approximately equal to that observed in the field after several years of traffic. During recompaction of the mixture a Gyratory Shear index (GSI) is determined from a printout of the mix strain. Past studies have also shown that the GSI correlates very well with rutting.

Two 4"-diameter specimens were compacted in a rotating base, slanted foot mechanical Marshall compactor (Fig. 9). Every time the hammer is lifted the base supporting the mold assembly rotates 110° (Fig. 10). The foot of the hammer has a 10 slant. The combination of rotating base and slant in the foot provides a kneading action during compaction, and generally results in higher densities compared to the conventional static base mechanical Marshall hammer. Seventy five blows were applied on each face of the specimen.

Two **4"-diameter** specimens were compacted (75 blows per face) in a conventional static base mechanical Marshall compactor (Fig. 9) used by most states including Pennsylvania.

All six specimens compacted by the three methods were tested for bulk specific gravity, voids in the total mix (l/TM), Marshall stability and flow at 140°F.

One core **(C6)** was taken beside Core **C7** as shown in Fig. 5. Aged asphalt cement was recovered by the **Abson** method from this core and tested for penetration at 77°F and viscosity at 140"F.

**Rut Depth Measurements**

A transverse surface profile of the lane adjacent to Cores C7-C11 (Fig. 5) was obtained at the time cores were obtained in spring of 1989. A 12-foot level straight edge was intended to be used (Fig. 11) to measure offsets at one-foot intervals across the lane to obtain the pavement surface profile (including the cross slope or **superelevation)** and measure surface rut depths. Cores taken transversely across the pavement were used to help determine the amount of rutting in the top layer and the underlying layer(s). This was done by drawing a profile of the layers using the core layer thicknesses. The amount of rutting was determined for the top layer by subtracting the rut depth in the second layer from the rut depth in the top layer. The rut depth in the second layer was determined by subtracting the rut depth in the third layer from the rut depth in the second layer. These rut depth values for a given layer were then correlated to the mixture properties of the same layer to insure a meaningful correlation.

It was determined that a taut level string line was used in lieu of the straight edge as planned. Since the string line sags and gives inaccurate surface profile and rut depths, it was decided to remeasure the transverse surface profile using a transverse profilograph device (Fig. 12). The profilograph device consists of a 14-foot straight reference beam/track which supports and guides a recorder. Afresh chart is installed on the recorder's drum, the recorder's sensing wheel is lowered to contact the pavement, the felt tip marker is adjusted in height as well as pressure, and the recorder is manually rolled along the beam across the lane. The resulting recording displays the vertical pavement profile (including its ruts) across the pavement. Horizontal distances are recorded to the scale of 1 foot = 1 inch. The beam was levelled so that the cross slope or superelevation was also displayed. Revised surface profiles were obtained during the summer of 1990 (about 1 1/4 year later than the core sampling).

Transverse profilographs were taken at the worst site (where CoresC7-C11 were taken) and at another site more representative of the project, preferably within 500 feet of the worst site.

## PROJECT DETAILS AND TEST DATA

### Project Location Details

Originally, the plan was to evaluate 35 sites. However, Site No. 21 was deleted by PennDOT and, therefore, there is no data for this site in this report. The locations of the remaining 34 project sites scattered across Pennsylvania are shown in Fig. 13. Table 1 gives the location details such as Engineering District, county, State Route (SR) number, Legislative Route (LR) number, section number, segment or milepost. This table also gives the year of construction of the last HMA overlay, whether the HMA is underlain by PCC pavement or not, and the condition of the pavement based on the maximum surface rut depth determined by the transverse profilograph. The pavement condition rating was subjectively determined for each pavement as follows:

| Max. Rut Depth (inch) | Age of the Overlay, Years | Rating |
|---|---|---|
| 0-1/8 | ... | Excellent (E) |
| 1/8-1/4 | >3 | Excellent (E) |
| 1/8-1/4 | $\leq 3$ | Good (G) |
| 1/4 - 3/8 | >3 | Good (G) |
| 1/4 - 3/8 | $\leq 3$ | Fair (F) |
| 3/8 - 3/4 | >3 | Fair (F) |
| 3/8 - 3/4 | $\leq 3$ | Poor (P) |
| > 3/4 | --- | Poor (P) |

The preceding subjective rating proved to be fairly reasonable on subsequent rut depth/traffic load data analyses which will be discussed later.

Only 4 of the 34 projects did not have PCC pavements underneath the HMA overlay. The age of the HMA overlays as of 1990 summer ranged from 2 to 19 years. Of the 34 projects, 10 were excellent, 9 were good, 12 were fair, and 3 were poor based on the rating discussed earlier. There was an assignable cause for the poor performance of Project 11 on Interstate 90. The HMA overlay was placed on a seal coat which was tack coated excessively and, therefore, provided a slip plane for rutting to occur. Therefore, Site 11 was removed from the data base for statistical analysis.

### Traffic and Climatological Data

Table 2 gives the traffic data such as average daily traffic (ADT), percentage of trucks, HMA overlay age as of 1990, and total 18-kip equivalent single axle loads (TESAL's) applied to the HMA overlay as of 1990. Since the data on ESAL's per day was available only for the current year, a traffic growth rate of 10% per year was assumed to calculate the total cumulative ESAL's applied to the pavement since construction. According to FHWA statistics the average increase